

# Radio Astronomy

R. M. Taylor

Deep Space Network Operations Section

R. N. Manchester

Division of Radiophysics, CSIRO, Sydney, Australia

*This article reports on the activities of the Deep Space Network in support of Radio and Radar Astronomy operations during July and August 1980. A brief update on the OSS-sponsored Planetary Radio Astronomy experiment is provided. Also included are two updates, one each from Spain and Australia, on current Host Country activities.*

## I. Introduction

Deep Space Network (DSN) 26-, 34- and 64-meter-antenna stations are utilized in support of experiments in three categories: NASA Office of Space Science (OSS), Radio Astronomy Experiment Selection (RAES), and Host Country.

## II. Radio Astronomy Operations

### A. NASA OSS Category

During this period support has increased for the series of ALSEP/Quasar VLBI observations to 56 hours of station time. Support for Pulsar Rotation Constancy observations has continued at prior levels at the Goldstone and Madrid 26-meter antenna stations. Similarly, the Planetary Radio Astronomy experiment has enjoyed a consistent level of support. The following is a brief summary of the status of this activity.

#### Planetary Radio Astronomy (OSS196-41-73)

1. **Observational objectives.** These objectives are twofold: first, to study the variations in synchrotron emissions from

Jupiter's radiation belts and, second, to make precision measurements, over a long period, of atmospheric stability in the outer planets.

### 2. Observed results.

- (a) Synchrotron variations change on time scales of days or months or years.
- (b) Data must cover 11 years for solar wind and long-term orbital parameters.
- (c) In collaboration with Professor E. Gerard of Nancay Observatory, France, a concentrated 6-hour-per-day observation effort (at the Madrid 26-meter station) for three months at 21 cm in early 1979 produced good Jovian short term variation data from which publication of the results is eagerly awaited.
- (d) Radio astronomy can make high precision, consistent measurements year after year and, thus, is very useful for studying atmospheric stability and seeking correlation between atmospheric changes and other natural variations such as solar flux. These studies involve the

outer planets and require long-term observations in order to detect large-scale time changes.

### 3. Implications.

- (a) It is interesting to try to determine the correlation, if any, of the synchrotron variations with solar parameters, orbital parameters, solar wind parameters and other natural phenomena.
- (b) What mechanism causes this type (source function) of variations?
- (c) How deep in planetary atmospheres can we detect climatic changes? Certainly to 10 atmospheres in the outer planets. Long-term observations are required, over several years. For example, the equatorial-to-pole temperature variation of 30 to 35 percent in the planet Uranus changes in a 22-year cycle. Can we detect climatic changes in the troposphere?

4. **Future interest.** In the Jupiter Patrol experiment the future looks toward millimeter or submillimeter observations but useful work could be done between 20 and 24 GHz in the molecular line area with a 64-meter single telescope. K-band interferometry looks like an exciting, realizable prospect in the near future. The question of why choose the DSN when the Very Large Array is available is answered by the Southern Hemisphere view not seen by the Very Large Array. It would be exciting to record the waterline spectra of planetary objects, including comets, in the Southern Hemisphere.

5. **Deep Space Network contribution.** The DSN provides facilities which have a long-term base, consistently high quality, stable instrumentation with continuity and instrument traceability and well-calibrated antennas. Planetary Radio Astronomy provides the DSN with a calibration base and a list of radio sources. The remaining problem with the facilities is that of blind pointing accuracy, a problem which is being resolved at this time.

## B. RAES Category

1. **RA 175.** On June 13 and 14 and again on July 1 and 3, 1980, for a total of 51 hours, the Goldstone 26-meter station supported VLBI observations of the source SS 433 (1909+04). These observations represent continuing efforts in support of the experimental objective of resolving this bizarre galactic object to determine its angular radio structure and, if possible, its origin. These activities will continue in a similar fashion at regular intervals until the end of the year.

2. **RA 137 Quasar Patrol.** Dual polarization Very Long Baseline Interferometry (VLBI) observations were made on

July 31 and August 1 at the Goldstone and Madrid 64-meter antenna stations of the source 3C454.3. Other telescopes supporting this experiment were Onsala, Sweden (26-meter), Haystack, Massachusetts (26-meter), Owens Valley, California (40-meter), Fort Davis, Texas (26-meter), Green Bank, West Virginia (40-meter).

The experimental objective was to observe the source in dual polarization, that is, right circular polarization and left circular polarization, as part of a scheme to construct a radio map of the region surrounding the quasar. Recordings were made using the Mark II VLBI Data Recording System. One of the principal investigators, Dr. William Cotton, of NRAO was in attendance during the experiment at the Goldstone 64-meter antenna station. Due to the failure of one of the S-band masers at Goldstone, it was not possible to record dual polarization simultaneously, so a time sharing technique was adopted, observing primarily in left circular polarization.

At this time, data reduction and analysis is in progress and the published results are anticipated in the near future.

## C. Host Country

The primary host country activity in Spain is the Instituto Geografico Nacional Interferometric Survey (IGNIS) project. The objectives of this activity are:

- (1) To conduct VLBI measurements of the relative position vectors between the 34- and 64-meter-antenna stations at Robledo de Chavela, the 26-meter-antenna station at Cebreros and comparison with other geodetic techniques.
- (2) In cooperation with other agencies involved in geodetic VLBI to exchange information on the following:
  - (a) Scale and orientation of the European Geodetic Net.
  - (b) UT1 and polar motion.
  - (c) Lithospheric plate motion.
- (3) Software development for post correlation data processing.

From time to time, when scheduled, observations are performed using the bandwidth switching technique in order to obtain the synthesized delay and fringe rate observables. Early results, reduced and analyzed in an IBM 370/158 computer with JPL-generated software, show the following baseline components and length of the Cebreros 26-meter to Robledo 64-meter baseline vectors in a right-handed coordinate system

with the Z-axis directed to the Continental International Origin and the X-axis along the Greenwich Meridian:

$$B_x = -2392.192 \pm 0.028 \text{ m}$$

$$B_y = -10015.228 \pm 0.011 \text{ m}$$

$$B_z = 1797.116 \pm 0.019 \text{ m}$$

$$\text{Total length} = 10452.607 \pm 0.013 \text{ m}$$

In order to compare these results with those of classical methods, several previous surveys performed during the last 10 years in this zone were reanalyzed. The analysis indicated that the compatibility between the different surveys is not assured due to various reoccupation problems of the common points and the existing uncertainty regarding the altitude of the geoid over the ellipsoid in this zone. Nevertheless, the difference between the VLBI and the classical results is 18 centimeters.

Planning for the future includes the following objectives:

- (1) Perform a new survey by tridimensional methods (laser, vertical deflection, etc.) for comparison purposes.
- (2) Make VLBI measurements of the relative position vectors between the three antennas.
- (3) Participate in European and transcontinental projects related to geodetic and geophysical applications of VLBI.

The only host country activity being supported in Australia during this period has been the pulsar observations being conducted for the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia. The observations are conducted almost exclusively at the 26-meter-antenna facility at Honeysuckle Creek. The following is a brief summary of the status of this activity prepared and submitted by R. N. Manchester of the Division of Radiophysics of CSIRO, Sydney, Australia.

### III. Pulsar Observations Using DSN Facilities in Australia

Since May 1975 a program of pulsar radio science observations has been carried out using the 26-meter-antenna station at Tidbinbilla, and more recently the similar facility at Honeysuckle Creek. The objective of this program is to determine accurate positions and pulsational periods for a set of southern pulsars and to monitor variations in the observed period. To achieve this objective a regular series of observations of pulse

arrival times is required with an antenna and receiver system which has stable characteristics over long time intervals (several years) and high sensitivity at a radio frequency in the L- or S-bands. An accurate time reference is also required. Since the Deep Space Network provides an S-band system with these characteristics it is ideal for this program.

Pulsars were first discovered in late 1967 by Antony Hewish and Jocelyn Bell of the Mullard Radio Astronomy Observatory, Cambridge, England, using a large 80-MHz array designed to study interplanetary scintillations of compact radio sources. Several time-varying sources not attributable to scintillation were detected. After further investigation it was realized that the emission from these sources was unlike that from any other natural celestial radio source and consisted of a series of regularly spaced pulses. The pulse interval was typically about 1 s. Publication of this result triggered a large effort at many radio observatories to understand these sources and to detect new examples. The searches have been very successful, with over 300 pulsars now known.

In 1968 the Molonglo radio telescope in Australia detected a relatively strong pulsar near the center of the Vela supernova remnant, which had the very short period of 89 ms. At about the same time a pulsar was detected by Green Bank, West Virginia, near the center of the Crab nebula (a well-known supernova remnant whose birth was observed by the Chinese in A.D. 1054), which had an even shorter period of 33 ms. The detection of these two pulsars and the subsequent observation that the pulsation period was increasing at a slow but regular rate established that pulsars are born in supernova events and consist of rapidly rotating neutron stars. By some means not yet fully understood the neutron star emits a narrow beam of intense radiation and we observe a pulse each revolution of the star as the beam sweeps across the earth. A neutron star, which is one of the possible end points of the evolution of normal stars, is an extremely compact star with a mass about equal to that of our sun but a radius of only 10 km or so. Only a star as compact as this could survive rotation at speeds up to 30 revolutions per second (1800 rpm!).

In general, pulsar periods are very stable and predictable. Typical rates of change are less than one part per billion per day and many are predictable to better than one part in  $10^{12}$ . However, some pulsars are subject to unpredictable changes in period. In the Vela pulsar these changes are more dramatic than for any other known pulsar. On four occasions since its discovery the Vela pulsar period suddenly decreased by about 200 ns (two parts in a million) and then, after some perturbations, resumed its normal rate of increase of about 11 ns per day. These period jumps are thought to be caused by a change in the moment of inertia of the neutron star and correspond to a shrinking of the stellar radius by about 1 cm. Observations

limit the time taken for the change to less than a week or so, but theoretical models suggest that it occurs within minutes. Since observations began at Tidbinbilla, two of these jumps have been observed, one in October 1975 and the other in July 1978. Figure 1 shows these two discontinuities in the otherwise regular increase of period.

Closer examination of the data shows that the rate of period increase is greater after the jump than before by about 1 percent and that this excess rate decays away on a time scale of a few years. In fact, the Tidbinbilla observations show that decay after the 1976 jump was still occurring at the time of the 1978 jump. This increase in period derivative followed by an approximately exponential decay suggested a model in which the neutron star consists of two main parts, a solid outer crust (probably a lattice of iron atoms) and an inner superfluid consisting largely of neutrons. Figure 2 shows the result of fitting this model to the Tidbinbilla and Honeysuckle Creek data. The parameters for the two jumps obtained from this fit are important constraints on the model. In particular, there are important differences in the post-jump recovery for the two events which cannot be accounted for in the simple version of the model.

Figure 2 shows that, while the model provides a close fit to the observed variations, the fit is not perfect. On top of the other variations the period appears to wander in random fashion. These fluctuations are very small (about one part in

a billion per year) and quite unpredictable, but nevertheless they are significant and are present to a greater or lesser extent in all pulsars. Several of the pulsars monitored at Tidbinbilla and Honeysuckle Creek show relatively strong period fluctuations. Analysis of these results is giving further information on the interior structure of neutron stars.

Besides the Vela pulsar the only other large period discontinuity observed was also detected at Tidbinbilla. In November 1977 it was discovered that the period of the pulsar PSR 1641-45 had decreased by about 90 ns or two parts in  $10^7$ . The post-jump recovery seems to be well fitted by the exponential decay model in this case also. Two similar events have been observed in the Crab pulsar, but both were much smaller, about one part in  $10^8$ .

The Vela events occur on average approximately once every three years, so we are about due for another one. Regular observations of this and the other pulsars are continuing at Tidbinbilla and Honeysuckle Creek with the cooperation of the Director of the Canberra Deep Space Communications Complex and the staffs of the stations. Along with similar programs at Goldstone and Madrid operated by G. S. Downs (JPL) these observations form the only long-term monitoring of pulsar periods and their variations currently being undertaken. The Deep Space Network is therefore fulfilling a unique and valuable role for radio science which we hope will continue and expand in the future.

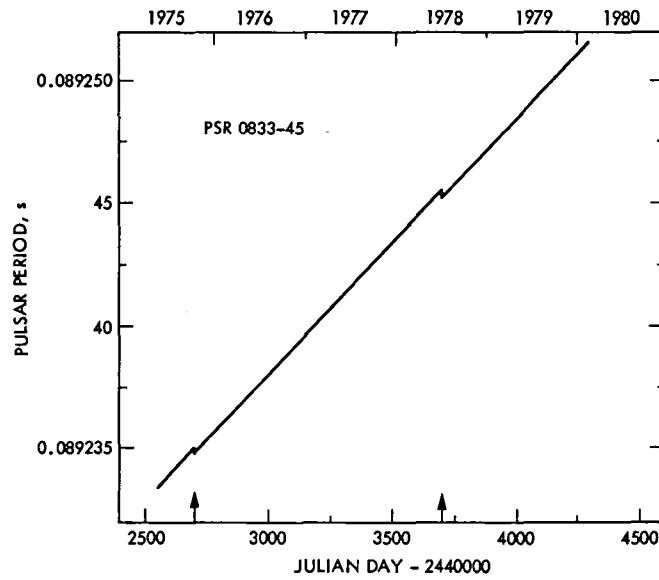


Fig. 1. Observed variations in the intrinsic period (i.e., after correction for doppler shifts resulting from the Earth's motion) of the Vela pulsar, PSR 0833-45, over the five-year interval, 1975-1980. The two period jumps are indicated by the arrows on the lower axis

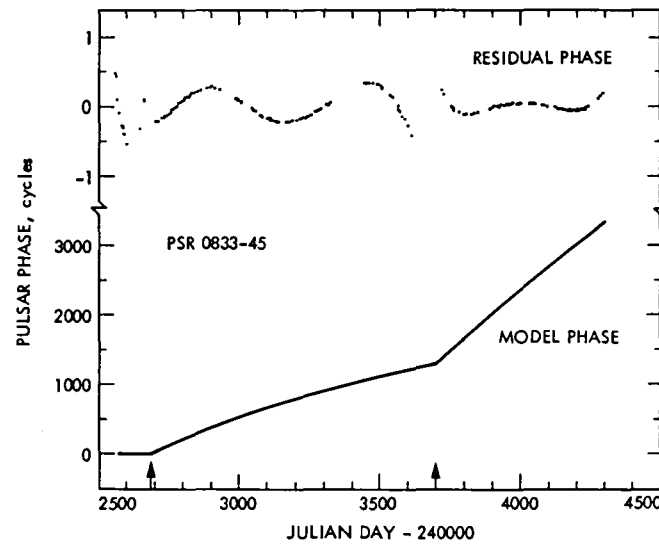


Fig. 2. Results of a fit of an exponential post-jump decay model to two period discontinuities observed in the Vela pulsar, PSR 0833-45. The lower part of the figure shows the model contribution to the observed pulse phase; the upper part of the figure shows the phase residuals after the fit. The two period discontinuities, indicated by arrows on the lower axis, each result in a discontinuous change in the gradient of the model phase.